

**Clandestine Skies: The Top-Secret History of Meteorological Satellites**  
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NOTE: This is the original version of the article that was published in the September / October issue of *Weatherwise* magazine. This version includes longer technical descriptions and both sidebars, “The Kármán Line: Where Space Begins” and “Pioneers of Space.”

At 5:26 pm on June 25, 2024, a SpaceX Falcon Heavy rocket thundered into the sky from Florida’s Kennedy Space Center and soared over the Atlantic Ocean. Inside the heavy-lift booster’s shrouds, the GOES-U weather satellite awaited its release to transfer onto a geostationary orbit 22,236 miles above the planet’s surface. The 11,000-pound GOES-U comprises seven primary instruments to collect data on weather events, oceanic dynamics, and solar output to support all types of industries and fields. One of the most advanced meteorological satellites ever designed, GOES-U represents the pinnacle of several generations of continuously advancing innovation.

The developmental history leading to systems like GOES-U began several years before the dawn of the Space Age with nascent concepts for space-based meteorological observation. Like many technological fields that emerged in the 20<sup>th</sup> century, meteorological satellites arose out of Cold War imperatives cloaked in secrecy. As such, many details of their emergence remained shrouded for years as their evolution was tied to clandestine reconnaissance platforms and military capabilities. Over the decades, the U.S. government has declassified troves of documents about these initial systems, the release of which has more fully

illuminated their origins. The early history of these satellites is a complex and often labyrinthine story filled with forward thinking pioneers, intrigue, tremendous risk, and technological breakthroughs. This work has culminated in one of the most important classes of technology in use today, one that enhances all industries, fields, and walks of life throughout the world.

### **First Glimpses and Initial Operational Concepts:**

On October 24, 1946, a modified German V-2 rocket blasted off from Launch Complex 33 at the U.S. Army Ordnance Proving Grounds at White Sands, New Mexico. Part of the U.S. military's classified "Project Hermes" weapon systems development initiative, the rocket, identified as V-2 Number 13, carried several scientific and meteorological research instruments, including an ultraviolet spectrograph to detect solar radiation and a smoke system to measure high-altitude winds. It also carried a 35mm motion picture camera loaded with black-and-white film housed in a reinforced cassette. Three minutes after lifting off, the V-2 reached its suborbital zenith at an altitude of 65 miles, just above the level that has since become recognized as lower space (see Sidebar 1: The Kármán Line: Where Space Begins). The rocket then fell back to Earth, the impact of which gouged a crater where specialists recovered the cassette in the wreckage.

Once processed, the film revealed breathtaking views of 1.5 million square miles of the western United States, the curvature of the Earth, and the darkness of space beyond. The images also showed large banks of clouds, distinctly visible above the planet's surface. While lionized in history as the first photographs of Earth from space, the images are just as notable for providing the first space-based views of meteorological phenomena. More than a decade before the launch of Sputnik 1 and

the beginning of the Space Age, Project Hermes had unintentionally provided substantial, practical examples of the utility of a hypothetical meteorological satellite.

The concept for human-made satellites was initially formalized in the United States in 1945 in the aftermath of Germany's World War II surrender. America's military, recognizing the technological advances made by German scientists in the fields of aerospace and weapon systems, undertook Project Overcast and Project Paperclip to seize as much of this information as possible (and deny the Soviet Union from accessing it). The top-secret initiative captured troves of technical details and tons of matériel, including V-2 rockets and support systems. Project Paperclip also relocated more than 1,600 German scientists to the United States, notably Wernher von Braun, the lead developer of the V-2 (see sidebar 2: Pioneers of Space). Von Braun was a champion of space exploration, including the development of artificial satellites to place into Earth orbit for a variety of purposes, including atmospheric science applications.

According to a declassified 1966 Air Force historical document, *The Air Force in Space*, the Army Air Forces (the predecessor to the U.S. Air Force) became interested in space travel after discovering German work on the concept. It notes the capture of German drawings of a prospective "large, manned space station" and other applications, both military and scientific. The document further describes early ideas by the Army Air Forces about the prospect of militarized spaceships, and includes a passage from the commanding general of the Army Air Forces, General Henry "Hap" Arnold, from his *General Arnold's Third Report*, dated November 12, 1945: "This can be done with true space ships, capable of operating

outside the earth's atmosphere. The design of such a ship is all but practicable today; research will unquestionably bring it into being within the foreseeable future." In December of 1945, the Army Air Forces Scientific Advisory Group endorsed the idea. In March of 1946, the Navy Bureau of Aeronautics proposed an interservice space program, with the development of satellites a key pillar of the concept.

In May of 1946, Project RAND, a research and development component of the Douglas Aircraft Company, produced an exhaustive study on space travel titled *Preliminary Design of an Experimental World-Circling Spaceship*. The classified report provides several potential applications that a satellite program might support, including gravity studies, solar research, and astronomy. Notably, the report states of meteorology:

“From a satellite at an altitude of hundreds of miles, circling the earth in a period of about one and one half hours, observations of the cloud patterns on the earth, and of their changes with time, could be made with great ease and convenience. This information should be of extreme value in connection with short-range weather forecasting, and tabulation of such data over a period of time might prove extremely valuable to long-range weather forecasting. A satellite on a North-South orbit could observe the whole surface of the world once a day, and entirely in the daylight.”

The U.S. military conducted several more suborbital V-2 flights from White Sands after the October 24, 1946 launch, many of which returned dramatic images of

clouds from space. The classified document *Upper Atmosphere Research Report No. IV*, published by the Naval Research Laboratory on October 1, 1947, includes a chapter titled “Photography from the V-2 at Altitudes Ranging up to 160 Kilometers.” The report comprises several revealing images of cloud forms from V-2 Number 21, which lifted off on March 7, 1947 and roared to an altitude of 101 miles above sea level. The document notes that “Photographs of this type are very useful for meteorological cloud studies....”

The January, 1949 issue of the *Bulletin [of the] American Meteorological Society* includes a paper titled “Cloud Observations from Rockets” by Air Force Major Delmar Crowson. Illustrated with film images from V-2 Number 21, the article describes how meteorologists could use space-based cloud photographs to complement surface- and atmosphere-based instrument readings to provide more comprehensive meteorological characterizations and forecasts. Crowson further discusses the possibility of using a television system for space-based transmission of cloud images for expedient review by meteorologists to augment their forecasts. The Radio Corporation of America (RCA) had released a series of successively higher quality television cameras throughout the 1930s and 1940s, some being prospective candidates for satellite use. At the time, however, meteorologists didn’t consider remotely sensed cloud imagery important for their forecast processes and thus dismissed Crowson’s ideas. They exclusively used measurements like temperature, humidity, and wind information collected in situ (directly at the point of interest) from ground stations and weather balloons and thus saw little need for such imagery.

In late 1948, The Rand Corporation, recently detached from the Douglas Aircraft Company as an independent non-profit thinktank, began an intensive initiative to study all practical uses of satellites, notably those equipped with “photographic and television equipment.” The document *Space research in the early years at Rand*, published in 1986 and declassified in 2022, explains that one of the key benefits of prospective satellites that Rand personnel identified during this period was their inherent immunity from being “brought down with present weapons or devices.” Rand’s work focused on potential for military reconnaissance uses, prompting the U.S. Air Force to commission further, more detailed study into a satellite photoreconnaissance system. In 1951, Rand produced the classified report R-217: *Utility of a Satellite Vehicle for Reconnaissance*, which analyzes various considerations and components of a prospective spy satellite program developed to gain imagery of enemy activity. R-217 includes sections on orbits and ground coverage, reconnaissance by television camera, satellite control, and power systems. It covers “weather reconnaissance” only briefly as Rand considered this topic to be so critical to military operations and to the success of an imagery reconnaissance satellite that they produced a classified companion report, R-218: *Inquiry into the Feasibility of Weather Reconnaissance from a Satellite Vehicle*.

Authors Stanley Greenfield and William Kellogg begin R-218 by emphasizing the critical military necessity of possessing systems to collect meteorological data in enemy areas. “Flying high above the sensible part of the atmosphere, so that atmospheric drag becomes negligible, the satellite becomes an unparalleled instrument for weather reconnaissance when scope of view is considered.” They outline a satellite that flies at an altitude of 350 miles above the Earth’s surface, completing an orbit once every one hour and 36 minutes. The authors proffer that a

satellite equipped with a television camera could gather images of clouds for real-time intelligence. According to them, specialists could then determine specific cloud types based on albedo (reflectivity) values and use this information to create basic forecasts. Greenfield and Kellogg explain that this information could also be used as a complement to traditional forms of weather forecasting, echoing Crowson's outlook. The paper also emphasizes that satellites could gather data for areas devoid of weather instrumentation, such as oceans and vast expanses of deserts. Furthermore, the wide area coverage provided by satellites could be used to gauge the accuracy of synoptic forecasts generated by newly-introduced numerical weather prediction models as sequential images illustrate weather pattern progression.

### **The Cold War and The Space Race:**

The Cold War, which emerged in the wake of World War II between the United States-led Western Bloc and the Soviet Union-backed Eastern Bloc, grew increasingly tense throughout the early 1950s. Both sides had rattled diplomatic sabers with the development and testing of massively powerful nuclear weapons and other advanced military systems. With the need for detailed views behind the Iron Curtain becoming more urgent, American research of military satellites would accelerate throughout the decade. This period also saw prospects of satellites and manned space stations enter public discourse throughout the world, with concepts originating outside of the confines of secretive thinktanks. In 1951, Soviet engineer Mikhail Tikhonravov began promoting the idea of creating a spaceship to carry cosmonauts to the moon and beyond. In March of 1952, American magazine *Collier's* began a 2-year, wildly popular series of articles called "Man Will Conquer Space Soon" chronicling the ideas of Wernher von Braun and other

rocket scientists. Topics covered in the series include satellites, manned spacecraft, lunar bases, and the exploration of Mars.

In the early 1950s, American physics professor Fred Singer began developing a concept called “MOUSE,” “Minimum Orbital Unmanned Satellite, Earth.” He proposed a 100-pound orbital craft packed with sensors, a magnetic storage device, and a data transmitter. *Time* magazine published an article on the idea titled “Science: Space Mouse” in their May 17, 1954 issue, stating “It can measure the earth’s magnetic field, catch cosmic rays and observe the particles shot from the sun that cause the aurora.” Although Singer never built a functional MOUSE, the Franklin Institute of Philadelphia, Pennsylvania built a mockup for display. Another satellite concept emerged in September of 1954, this one specific to weather. American meteorologist Harry Wexler published the paper “Observing the Weather from a Satellite Vehicle” in the *Journal of the British Interplanetary Society*. Unaware of report R-218, Wexler makes points similar to those in the Rand work, but with an emphasis on scientific and general forecasting uses.

Military suborbital experiments, similar to those of Project Hermes, continued at a steady pace through the mid-1950s, with each flight demonstrating the benefits of space-based systems. On October 5, 1954, the U.S. Naval Research Laboratory launched a modified Aerobee sounding rocket from White Sands. Onboard, it carried two motion picture cameras, one of which was loaded with Kodachrome color film. Exposed from an altitude of 100 miles above the planet, the footage captured scenes of the planet’s surface from the central United States to Mexico’s Baja California Peninsula. The flight yielded several significant firsts: the first color images of Earth from space, the first color images of clouds from space, and

to the surprise of scientists, the first images of a tropical cyclone from space. Documented in the article “A Rocket Portrait of a Tropical Storm” by Otto Berg and L.F. Hubert (*Monthly Weather Review*, June 1955), the unclassified experiment was an unintended proof-of-concept for the ideas of Crowson, Greenfield and Kellogg, and Wexler. The presence of a tropical depression over the Big Bend region of Texas explained intense, un-forecast rainfall recorded at several weather stations throughout the area that had puzzled meteorologists. If provided with such imagery prior to the storm’s arrival, meteorologists could have augmented their traditional forecasts to account for increased precipitation.

When Dwight D. Eisenhower assumed the presidency in 1953, he prioritized the pioneering of space, making some aspects of this initiative very public while maintaining a cloak of secrecy over others. Deeply concerned about a pre-emptive Soviet nuclear attack—a “nuclear Pearl Harbor”—his administration sought to find ways to detect and observe the development, testing, and deployment of Soviet strategic weapons and general military capabilities. A key pillar of this strategy was the development of satellite systems to peer at Soviet developments. This new frontier of observation brought new concerns, including that Eastern Bloc countries might see overflights of American satellites as overt aggression. To preempt this, the administration promoted a concept called “freedom of space,” where no country could make a claim of sovereignty over outer space.

On July 29, 1955, the Eisenhower Administration announced that the United States would launch a science-oriented satellite during the forthcoming International Geophysical Year, or IGY. The IGY, which spanned from July 1, 1957 to December 31, 1958 was organized as an international scientific initiative to

promote the interchange of ideas in fourteen disciplines, notably meteorology, solar activity, and satellite research. Publicly, the proposed satellite launch would celebrate global unity under the banner of progress. Secretly, the Eisenhower Administration sought to use a scientific satellite as a trailblazer of the freedom of space concept for subsequent military reconnaissance satellite flights. Furthermore, Eisenhower sought for the United States to place a satellite into orbit first, establishing American primacy in the domain of space.

Four days after the Eisenhower Administration's announcement, on August 2, 1955, the Soviet Union made their own declaration of intent to place the world's first artificial satellite into orbit. The Eisenhower Administration's proclamation had begun the Space Race—although the United States had been conducting top-secret research into satellites for nearly a decade.

Public and institutional interest in satellite technology and its potential benefits for humanity burgeoned after the Eisenhower announcement. Much of this interest focused on meteorology. The October, 1955 issue of *Weatherwise* featured an article by Joseph J. Kelly titled “Earth Satellites: What Will They Mean to Meteorology?” The *New York Times* published “Man-Made ‘Moons’ Stir Meteorologists; Satellites Seen Solving Weather Riddles” on January 24, 1956. “The first man-made satellite to break through the “ion curtain” will produce important knowledge, the American Meteorological Society was told yesterday.” The *Times* article stated.

As public speculation and excitement mounted throughout the mid-1950s about the prospects of satellites, government research continued at a brisk pace. Several

projects emerged for satellite development, conducted by the Army, Navy, and Air Force, with varying degrees of cooperation among these services. This work fell into two categories, publicly heralded scientific initiatives, and extremely secretive work on satellites for military applications, particularly reconnaissance systems. The Soviet Union maintained a similar dichotomy, with the U.S. and U.S.S.R. each concealing all military work while publicly touting progress of scientific applications.

The U.S. Army program, headed by Wernher von Braun in the Army Ballistic Missile Agency (ABMA), forged ahead with an initiative called Project Orbiter. The Navy developed Project Vanguard with the goal of placing a satellite in orbit during the International Geophysical Year and accomplishing at least one significant scientific feat with it. The Air Force undertook a complex, extraordinarily secretive program rooted in work by the Rand Corporation called Project Feed Back that would eventually yield the first operational reconnaissance satellite. Work by all would eventually contribute to future meteorological satellites.

On October 4, 1957, the Soviet Union stunned the United States by successfully placing the world's first artificial satellite into orbit, Sputnik 1. Launched using a modified R-7 intercontinental ballistic missile, the feat marked the opening of the Space Age, with the Soviets claiming a firm lead in the Space Race. The technological demonstration roiled the Eisenhower Administration, spiking anxiety about the Soviet's ability to weaponize space and deliver nuclear weapons within an hour from the other side of the globe. The Soviet's lead was emphasized by frequent media reports of Sputnik 1 sailing over the United States, freely in space,

as per Eisenhower's doctrine. The Soviets then launched the world's second artificial satellite, Sputnik 2, on November 3, carrying the first living creature into space, a dog named Laika. The administration scrambled to salvage America's path to space primacy, expediting the most promising programs and reorganizing the country's myriad anfractuous initiatives into a more synchronized effort, coalescing a unified national space program.

On January 31, 1958, just under four months after the Sputnik 1 milestone, the U.S. successfully launched its first orbiting satellite, Explorer 1. The success was a result of a hastily resurrected Project Orbiter, which had been shelved to focus on the Navy's Project Vanguard. Developed by a team led by Wernher von Braun at the Army Ballistic Missile Agency, Explorer 1 carried a cosmic ray detector that led to the discovery of the Van Allen radiation belts. The proof-of-concept system paved the way for more advanced innovations, including those related to meteorological observation.

America's second successful satellite, Vanguard 1, entered orbit on March 17, 1958. Developed by the Naval Research Laboratory as part of Project Vanguard, the 6-inch diameter spherical satellite pioneered the use of solar power in space with its six photovoltaic panels mounted on its exterior. The Navy sought to test the rocket that boosted Vanguard 1 to orbit and to ascertain the effects of the space environment on satellite componentry. Project Vanguard also included a tracking system called Minitrack, which scientists used to make precise measurements of the satellite's orbit. The satellite's solar panels allowed the onboard Minitrack transmitter to function for more than six years (an onboard battery supplied usable

power for just 20 days). Slight variations of Vanguard 1's motion contributed important information about the Earth's gravitational field and its shape.

Scientists also used the satellite and the Minitrack system for upper atmospheric measurements. Slight deviations of Vanguard 1's trajectory, caused by aerodynamic drag, led researchers to conclude that the upper atmosphere was denser than previously understood. Scientists also discovered that the outer atmosphere expanded and contracted with changes in solar output. Although Vanguard 1 was not purpose-built for meteorology, the discoveries it helped produce marked the first time atmospheric science experiments were conducted using a satellite.

## **Vanguard 2**

As part of the Eisenhower Administration's space program reorganization initiative, the government added two key agencies in 1958, ARPA and NASA. The Department of Defense established ARPA (Advanced Research Projects Agency) on February 7, 1958 to coordinate military efforts related to space technology innovation. In July of 1958, NASA began operations to tackle civilian and scientific space goals. Despite the distinction, ARPA and NASA would work together on several space system projects, including the first purpose-built meteorological satellite.

Specialists developed the satellite system to provide data to undertake three primary meteorological missions: to study cloud formations and how they evolve over time, to study the planet's energy budget based on cloud imagery, and to continue the research of upper atmospheric density begun by Vanguard 1.

Scientists would also analyze the satellite system's performance for future imagery uses, both for military and scientific applications. Formally described as the "cloud cover satellite," technicians fitted the body of the craft, a 20-inch diameter magnesium sphere, with two small telescopes, each focused on an infrared sensor. They also incorporated power and support systems including data storage, data transmission, and telemetry modules. Although the government publicly celebrated the satellite's scientific goals, the state-of-the-art instrument package it contained traced its development back several years to a top-secret Rand study, Project Feed Back.

The Rand Corporation embarked on Project Feed Back in the early 1950s after presenting reports R-217 and R-218 to the U.S. military. According to the National Reconnaissance Office in a historical document, Feed Back provided "highly evolved concepts for reconnaissance satellites." This included detailed analysis of satellite-based weather intelligence data collections to support prospective reconnaissance satellite missions and military operations. After careful review of Feed Back reports, the Air Force's Air Research and Development Command began a top-secret project called Weapon System 117L, or WS-117L, the United States' first military orbital space program.

WS-117L involved work with several defense contractors, including RCA, which proposed a television infrared weather satellite to support military reconnaissance operations. Infrared imaging could be used regardless of ambient lighting conditions—day or night—making it ideal for up-to-date reconnaissance information. RCA's work with infrared sensors and imaging dated to the mid-1930s with their development of the "sniperscope" and "snooperscope," infrared

night vision systems. In 1950 the company innovated the breakthrough “Vidicon,” a television camera tube that performed far more effectively than previous technology and could be configured to respond to infrared light.

RCA’s proposed television system reconnaissance satellite, equipped with a tape recorder, would allow data transmission as soon as the satellite was in range of a downlink facility. Although the Air Force ultimately passed on RCA’s plan, the Army Ballistic Missile Agency embraced the concepts for cloud observation, and work began at RCA’s new Astro-Electronics Products Division. The Army Signal Corps and ARPA took control of the instrumentation program in 1958, with technicians from the Evans Signal Laboratory, part of the Army Signal Corps’ U.S. Army Signal Research and Development Laboratory, overseeing the work. RCA developed the sensors and precision optics company Perkin-Elmer crafted the telescope optics that would focus images of clouds onto the sensors. The Naval Research Laboratory, which developed the Vanguard rocket and the program’s standardized satellite body, initially managed the program.

The satellite was designed to rotate at 50 revolutions per minute along its longitudinal axis for stability as it orbited the planet. The RCA and Evans Signal Laboratory engineers developed the imaging system to scan one transect of the earth at a time, synchronized with the satellite’s spin. An entire scene would be built transect-by-transect in succession as the satellite progressed along its orbital trajectory. Despite the technology’s original military intent of scanning both day and night scenes, the satellite would only gather imagery of daylit regions of the planet as it was promoted as a scientific satellite. A photoreceptor would determine when each telescope was aimed at a sunlit portion of the planet and activate the

infrared sensor. The satellite's data would be recorded on a magnetic tape memory device that could be transmitted to a downlink center once in range. Scientists estimated that the onboard battery could power the system for approximately two weeks.

Despite its top-secret origin, the U.S. government promoted the scientific capabilities of the "weather eye" to media outlets including newsreels, newspapers, and magazines. Problems arose, however, related to determining what specific information could be publicly disclosed due to the bifurcated nature of the space program that the Eisenhower Administration created. With no firm guidelines established due to the novelty of the space program, both military-side and civil-side managers scrambled to promote scientific goals without jeopardizing national secrets.

On September 26, 1958, the Naval Research Laboratory launched a Vanguard rocket carrying the cloud cover satellite from Cape Canaveral, Florida. The rocket failed after its first stage, however, and the satellite, designated SLV-3 (Satellite Launch Vehicle 3), disintegrated in the atmosphere. Just days later, NASA took control of the program from the Navy as part of the space program's realignment plan. On February 17, 1959, NASA launched SLV-4, identical to SLV-3, on a Vanguard rocket. This time, the booster reached its intended destination in space. Once in orbit, NASA changed the name of SLV-4 to Vanguard 2, the world's first successfully deployed meteorological satellite and NASA's first successful satellite launch.

Despite the delivery into orbit, the third stage of the Vanguard rocket had nudged Vanguard 2 upon its release, introducing a wobble in its axial stabilizing spin. Although the satellite's imagery system functioned as designed, the wobble made assembling each recorded transect into a complete image impossible. Despite this, scientists were able to conduct upper atmospheric density observations, and the knowledge gleaned of the system's internal functions would contribute to subsequent generations of satellites, both scientific and military.

In addition to the Vanguard 2 launch, several other important events for the advancement of meteorological satellite development occurred in 1959. On October 13, NASA launched the Explorer 7 satellite into orbit carrying an array of scientific instruments including a system called a flat plate radiometer. The precision instrument, developed primarily by Finnish-American scientist Dr. Verner Suomi, comprised four detectors to measure Earth-bound solar radiation and infrared energy re-emitted by the planet's surface. The use of the system pioneered satellite-based analysis of the Earth's energy budget, which yields data critical to the study of the Earth's climate.

Also in October of 1959, atmospheric physics researcher Lewis D. Kaplan published the paper "Inference of Atmospheric Structure from Remote Radiation Measurements" in the *Journal of the Optical Society of America*. In it, Kaplan explains that "A detailed analysis of the structure of the atmosphere, including the three-dimensional distribution of temperature and water vapor, can be obtained from the spectral variation of its thermal radiation as viewed from a reconnaissance aircraft or earth satellite." The concept, eventually called "satellite sounding,"

would bridge the meteorological capabilities gap identified by Crowson and other early meteorology satellite theoreticians.

Kaplan's work was rooted in concepts of satellite-based infrared analysis of the atmosphere dating back to RCA's proposals for military weather reconnaissance satellites and the cloud cover system integrated into Vanguard 2. His work was also influenced by the 1956 paper "The Radiative Heat Transfer of Planet Earth" by researcher Jean King. King presented the paper at the 1956 Upper Atmosphere Rocket Research Panel and subsequently published it in the 1956 book *Scientific Uses of Earth Satellites* (edited by James Van Allen). The NOAA states that Kaplan's concepts, which would take several years to fully implement, "...transformed the field of weather forecasting, and arguably, the world."

### **TIROS, the Defense Meteorological Satellite Program, and Beyond**

RCA's work with weather satellites, which emerged out of the top-secret Weapon System 117L program, was not exclusive to the Vanguard 2 project. Working under the Army Ballistic Missile Agency beginning in 1956, RCA helped develop a meteorological satellite program far more robust than Vanguard 2, the Television InfraRed Observation Satellite, or TIROS.

Like other satellite projects during this period, the program that would become TIROS transitioned through several oversight agencies during its evolution. At first an Army Ballistic Missile Agency project named Janus and then Janus II, the Department of Defense shifted it to the Advanced Research Projects Agency in 1958 to satisfy a high-priority requirement for a military weather satellite, renaming it TIROS. Due to the Eisenhower Administration's outlook that a

weather satellite program should be helmed by a civilian agency, the project shifted again in 1959, to NASA control.

The initial concept for TIROS included a television camera suite based on the Vidicon system by RCA's Astro-Electronics Products Division, a flat-plate radiometer developed by Verner Suomi, and an infrared scanner based on the system used in Vanguard 2 developed at the Evans Signal Laboratory. After several design changes, the satellite, designated TIROS-1, carried two RCA Vidicon cameras, a wide-field imager with a field of view of 104° and a narrow-field camera with a 12.7° field of view. The wide-field camera had a resolution of approximately 3 miles and swept an area roughly 750 miles wide, and the narrow-field camera had a .25-mile resolution and swept an area approximately 75 miles wide.

Engineers crafted an 18-sided drum for the body of TIROS-1, 42 inches in diameter by 22 inches high. It was covered by 9,260 photovoltaic cells for power and comprised several subsystems, including radio receivers and transmitters, a battery system, and a magnetic tape data recording system. It was designed to rotate for stability, starting out at a rate of 136 revolutions per minute upon release and then slowing to 12 RPM, with onboard solid rocket boosters to maintain the 12 RPM rate.

NASA successfully launched TIROS-1 into an orbit 460 miles above the Earth on April 1, 1960. It functioned for 75 days, transmitting more than 23,000 images, 19,000 of which meteorologists deemed usable. The satellite's imagery enabled meteorologists to study several types of meteorological phenomena from above,

including large thunderstorms, storm fronts, and the effects of jet stream winds, among others. It also enabled meteorologists to observe the lifespans of multiple storm systems, including a tropical storm in the Atlantic Ocean. Researchers fused imagery data with in situ observations to refine numerical weather prediction models and develop new forecasting methods.

The spectacular success of TIROS-1 marked the beginning of operational satellite meteorology, and NASA launched several more TIROS satellites, including iterations with radiometers and infrared scanners. In less than 14 years, scientists had progressed from the first suborbital image of a meteorological phenomenon to a fully functioning weather satellite program. Each TIROS system flight provided more data for operational meteorology, atmospheric science research, and for subsequent meteorological satellite system development.

The next meteorological satellite program that the United States would launch would be undertaken in extraordinary secrecy—nobody outside a small group would know about its existence for decades. The development of the program originated with the same top-secret project that spawned Vanguard 2 and TIROS-1, the U.S. Air Force’s Weapon System 117L. In 1956, the WS-117L program spawned three distinct strategic reconnaissance initiatives, the Discoverer Program, the Satellite and Missile Observation System (SAMOS), and the Missile Defense Alarm System (MIDAS). “Discoverer” was a cover name for the top-secret Corona project, America’s first operational satellite reconnaissance program.

Ultimately operated by the Central Intelligence Agency and its National Reconnaissance Office, Corona captured images of areas of interest with a powerful film camera. Film was returned to the planet’s surface in re-entry

capsules called “film buckets,” retrieved mid-flight by special airplanes as they descended under a parachute. The precision optics and high-resolution film of Corona captured imagery with remarkable fidelity. Clouds, however, could render a mission a failure. Even a small cloud bank could obscure or completely block a location from satellite view. Images from the first successful Corona mission on August 18, 1960, revealed some areas almost completely covered in clouds. Satellite-based “cloud reconnaissance” would allow operators to know when Corona’s cameras could photograph a target, and when precious film should be reserved.

The U.S. military well understood the importance of cloud reconnaissance through experience with aerial photoreconnaissance missions from World War I through the Cold War. The government developed Corona, however, without a companion weather satellite for several reasons, notably resource availability. The Corona satellite, one of the most complex systems ever developed at the time, absorbed virtually all available military satellite development resources. The complex bureaucracy imposed by the Eisenhower Administration’s bifurcated space program also contributed to a slow procurement process.

At the time, NASA had been developing a meteorology program to satisfy both military and civil needs, the National Operational Meteorological Satellite System, or NOMSS. NOMSS, however, was in its nascency as a concept when Corona debuted; NASA didn’t plan on launching the system until 1963 at the earliest. TIROS-1, which had achieved operational success a few months before the first successful Corona mission, circled the planet on low-Earth, inclined equatorial orbit, with a 48.4° inclination angle. This meant that the satellite could only scan

locations on the planet between 48.4° north and 48.4° south latitude; Moscow and other key reconnaissance targets lie far outside this range.

In April of 1961, the National Reconnaissance Office answered this problem by initiating a top-secret project called “Program 35,” according to declassified CIA documents. Shortened to “P-35,” the program created a miniature TIROS satellite that comprised just one RCA Vidicon-based television camera. The CIA went to great lengths to conceal the purpose of the program, explaining that even people who worked on P-35 did not know how it would be used. “Program 35...was successfully represented to be a closely held space program with no covert or clandestine associations.” One top-secret CIA document reveals.

The first successful P-35 satellite reached orbit on August 23, 1962. Launched from Vandenberg Air Force Base, the satellite, designated “P35-2” flew on the same orbit as a Corona satellite, but slightly preceding it. The orbit, called a heliosynchronous or sun-synchronous orbit, is a type of polar orbit where a satellite passes over the same location of the planet at the same local solar time on each pass. The polar nature of the orbit provided Corona full Earth coverage, regardless of reconnaissance target latitude. The heliosynchronous form of the orbit provided CIA imagery analysts, called photointerpreters, the ability to gauge surface changes, notably through shadow analysis. The weather reconnaissance satellite would pass over a reconnaissance target and pass imagery back to National Reconnaissance Office specialists, and if clear of clouds, the specialists would clear the Corona satellite to begin photographing targets. Program 35 proved to be tremendously successful, although few would know its purpose for decades. The

program would evolve into the Defense Meteorological Satellite Program, or DMSP, today the longest-running American satellite program.

Meteorological satellite technology continued to advance rapidly through the 1960s and included the first weather satellites placed into orbit by countries other than the United States like the Soviet Union's Kosmos series. In the mid-1960s, the United States began operating the first geostationary meteorological satellites. These satellites orbit the planet at an altitude of 22,236 miles above the equator, with an orbital period matching the rotation of the Earth. Remaining stationary over a specific part of the world allows continuous environmental monitoring, critical to modern atmospheric science applications.

The GOES-U satellite, the Geostationary Operational Environmental Satellite-U, became GOES-19 after its successful placement into geostationary orbit. The system, which provides data to both civil and military users, is the last of the breed of GOES satellites, the first of which entered orbit in October of 1975. NASA and the NOAA plan on launching the first of the GeoXO, or the Geostationary Extended Observations, line of satellites in 2032, which will replace the GOES lineage. The debut of the GeoXO will continue the technological progression of these systems, a progression with little-known, top-secret origins.

### **SIDEBAR 1: The Kármán Line: Where Space Begins**

The region where the Earth's atmosphere transitions into space has proven difficult to define, with debate on the topic predating the dawn of the Space Age. The atmosphere does not abruptly end at a discrete physical juncture with space; it becomes less dense with altitude as it extends above the planet's surface. The bottom two layers of the atmosphere, the troposphere and the stratosphere, comprise more than 99 percent of the atmosphere's mass. Above the stratosphere, the top of which lies at an altitude roughly 31 miles above sea level, the tiny remainder of atmospheric mass is distributed among the mesosphere, the thermosphere, and the exosphere. According to the University Corporation for Atmospheric Science, some sources place the upper limit of the exosphere at 120,000 miles above the Earth's surface, slightly more than half the distance from the Earth to the Moon. Other sources state that the exosphere ends at 62,000 miles above the planet's surface. Beyond the exosphere, density continues to decrease to a near vacuum in interplanetary space, almost devoid of matter, but not completely.

Specialists from several disciplines have proposed various altitudes within this continuum as the boundary of space. Some have used atmospheric science as a basis, nominating the mesosphere. Others have proffered arbitrary values, such as the U.S. Air Force's 50-mile mark, which it instated in the 1950s as the altitude at which to grant astronaut status to pilots. Some legal authorities have objected to the establishment of *any* boundary due to potential restrictions and conflicts based on sovereign claims of air and space above a country. In his book, *The Never Ending Dispute: Delimitation of Air Space and Outer Space*, researcher Robert Goedhart explains that proposed boundaries have ranged from 30 kilometers (18.6 miles) to 1.5 million kilometers (932,000 miles). Most of these suggestions,

Goedhart notes, have ranged between 75 kilometers (46.6 miles) and 100 kilometers (62.1 miles).

In the mid-1950s, Hungarian-American aerospace engineer Theodore von Kármán defined the edge of space in functional terms. He proffered that the atmosphere ends and space begins where a human-made craft can no longer sustain its altitude through aerodynamic forces due to insufficient air density. At this point, the craft requires a flight system that relies on non-aerodynamic forces to stay aloft (for example, rocket thrust). In von Kármán's words, space is the altitude "where aerodynamics stops and astronautics begins...."

Although von Kármán never published his concept, he presented it informally at a conference attended by lawyer Andrew Gallagher Haley. Haley, a pioneer of space law, estimated the edge of space to be 84 kilometers (52.2 miles) based on von Kármán's reasoning and his own calculations of aerodynamic drag on satellites. In his 1958 book, *Space Law, the Development of Jurisdictional Concepts* (published by the American Rocket Society), Haley introduces the term "Karman primary jurisdictional line," which was retitled "Kármán Line" in the early 1960s. The Fédération Aéronautique Internationale (the World Air Sports Federation), which certifies world records for aeronautics and astronautics, subsequently publicized the altitude of the Kármán Line as 100 kilometers (62.1 miles). NASA, in an informational sheet, notes that 99.99997 percent of the Earth's atmosphere lies below the 100-kilometer altitude level.

While the United Nations and many practitioners have recognized the 100-kilometer Kármán Line as the reasonable boundary of space, it is not a legally

binding altitude, and not all have accepted its legitimacy. In his October 2018 paper “The edge of space: Revisiting the Karman Line,” published in *Acta Astronautica*, astrophysicist Jonathan McDowell of the Harvard-Smithsonian Center for Astrophysics argues that 80 kilometers (49.7 miles) is the most appropriate altitude based on several aerodynamic, physical, and historical criteria.

## **SIDEBAR 2: Pioneers of Space**

Technology that fostered the pioneering of space emerged in the early 20<sup>th</sup> century due to the work of several innovators. These visionaries included Konstantin Tsiolkovsky, Robert Goddard, Hermann Oberth, Max Vailer, Fritz von Opel, and Wernher von Braun.

Self-taught about the heavens as a youth, Russian physicist Konstantin Eduardovich Tsiolkovsky earned the title of “father of astronautics” through his research and writings. He released his most notable work, *The Exploration of Cosmic Spaces by Means of Reaction Devices*, in 1903, with a subsequent addition published in 1911. In these volumes, Tsiolkovsky outlines his concept for a multi-stage, liquid-fueled booster, the first time in history that a rocket was proposed for space travel. He also developed equations to compute escape velocity (the speed needed to break away from Earth’s gravitational field) and several other important engineering concepts important to astronautics. His work inspired many, including Soviet space theoreticians Mikhail Tikhonravov and Sergei Korolev, two of the most important pioneers of the Soviet space program.

Called the “father of modern rocket propulsion” by NASA, American physicist and inventor Robert Goddard became fascinated with the heavens as a youth. During his childhood, he gazed at stars with a small telescope, studied birds in flight, and pondered cloud forms. Intrigued with the concept of traveling to space, Goddard experimented with sounding rockets (used to take atmospheric measurements), then began innovating novel rocket designs and technology of his own. On July 7, 1914, the United States Patent Office issued him patent number 1,102,653, “Rocket Apparatus.” The patent describes a solid-fuel, multi-stage booster to “...transport photographic or other recording instruments to extreme heights.” Several other innovations followed, including one for a rocket fueled by either solid or liquid propellant. In January of 1920, the Smithsonian Institution published his book, *A Method of Reaching Extreme Altitudes*, distributing it globally. The book provides detailed analyses of prospective use of rockets for space travel, including for transport to the moon. A large portion of the 79-page treatise is devoted to the use of rockets for studying the atmosphere.

On March 16, 1926, Goddard launched the world’s first liquid-fueled rocket, which he named *Nell*, at a field in Auburn, Massachusetts. The flight, which reached an altitude of 41 feet, was one of the most important milestones in the history of space exploration as it proved the utility of liquid-fueled rockets. Goddard continued his work, creating several more powerful and higher-flying rocket designs, until his death in 1945.

Inspired by space travel stories written by French novelist Jules Verne and others, German physicist Hermann Oberth began experimenting with model rockets in 1908 at the age of 14. He published *Die Rakete zu den Planetenräumen* (*The*

*Rocket Into Interplanetary Space*) in 1923, which describes a hypothetical rocket for human transport. Crucially, Oberth explains that the rocket would be propelled by ethyl alcohol and liquid oxygen or liquid hydrogen and liquid oxygen—the latter combination being extremely energetic. A second edition was published in 1925, and a third (greatly expanded) version was released in 1929, with a new title: *Wege zur Raumschiffahrt (Ways to Spaceflight)*. Historians regard *Ways to Spaceflight* as one of the most important works in the history of astronautics due to Oberth’s detailed descriptions and formulas.

Oberth’s *The Rocket Into Interplanetary Space* sparked intense interest throughout the world in the prospects of space flight. One of those influenced was an Austrian named Max Valier, who enthusiastically promoted Oberth’s work in magazine articles and his 1924 book *Der Vorstoss in den Weltenraum: Eine wissenschaftlich-gemeinverständliche Betrachtung (The advance into space: A scientific and commonly understood view)*. In 1927, Max Valier founded “Verein für Raumschiffahrt” (Society for Space Travel) with Germans Johannes Winkler and Willy Ley. The group, of which Hermann Oberth became a member, would eventually develop several rocket designs, with some roaring to heights of more than 3,000 feet.

In 1927, Valier approached German automotive magnate Fritz von Opel with the idea of developing a rocket program. Valier sought to use rockets to propel Opel automobiles, then progress to powering aircraft with them, and then possibly create rocket spacecraft. Von Opel reacted enthusiastically to the proposition, in great part due to the publicity he felt it would generate for his company. The two then enlisted German rocket engineer Friedrich Wilhelm Sander, whose company

specialized in black powder-propelled signal rockets and maritime rescue rockets (which launched ropes). The program, called “Opel Raketenwagen” (“Opel Rocket Car”), shortened to “Opel-RAK,” was the first large-scale rocketry program in history. The Opel-RAK team developed several solid-fuel rocket-powered land systems in the late 1920s, including cars, a motorbike, and rail vehicles, the demonstrations of which drew large crowds. The enthusiasm generated by the exhibitions took on the name “Raketenrummel” (“Rocket Rumble” or “Rocket Craze”). The team also fitted solid-fuel rockets to a sailplane designed by German aeronautical engineer Alexander Lippisch, the “Ente” (“Duck”). The Duck became the first rocket-powered aircraft in history to fly when it roared into the sky on June 11, 1928.

Born on March 23, 1912, Wernher von Braun would become the most famous and influential of the pioneers of space travel technology. Like Goddard, von Braun became interested in space as a youth by exploring the skies with a telescope. At the age of 13, he read Hermann Oberth’s *The Rocket Into Interplanetary Space*, engendering a passion for the idea of rocket-powered space travel. His interest was further ossified by the Raketenrummel movement, which led him to create his own rocket-powered car using fireworks for propulsion.

Von Braun began studying at the Technische Hochschule Berlin (Berlin Technical University) in 1930, where he joined the Society for Space Travel and assisted Herman Oberth with liquid-fuel rocket experiments. The two eventually worked together on a series of rockets called “Aggregat,” German for “Aggregate” or “Assembly.” Walter Dornberger, a German artillery officer, began the extremely secretive Aggregat program to develop long-range ballistic missiles and rocket

artillery after the First World War. The Treaty of Versailles, which formally ended World War I, forbade Germany from conducting large-scale weapon system development, notably gun artillery.

Dornberger viewed weaponizing the emerging technology of rocketry as a way to circumvent the restraint, although the work would need to be conducted clandestinely. He bestowed the innocuous and vague name “Aggregat” to the program, explaining that it referred to the amalgamation of several systems that were synchronized with great precision (which rocket flight requires). Due to its military prospects, the German government allotted healthy amounts of resources to the program. The national-level funding would unintentionally yield the foundation of the Space Age.

Von Braun and other scientists toiled throughout the 1930s and 1940s on the Aggregat series. The first of the family, the Aggregat 1, or A-1, used an engine that burned ethanol and liquid oxygen and comprised a rudimentary inertial stabilization system. Although it exploded during its maiden launch attempt on December 21, 1933, the scientists created several successive iterative designs. On October 3, 1942, the Aggregat 4 (A-4) lifted off successfully, reaching an altitude of more than 50 miles on its maiden flight. On June 20, 1944, the A-4 design reached an altitude of 108.5 miles above sea level, the first human object to fly into space.

Germany used the rockets, each loaded with approximately 2,000 pounds of high explosives, to strike targets in England (primarily London), Belgium, France, and the Netherlands. The Nazi Propaganda Ministry, led by Joseph Goebbels, renamed

the A-4 “Vergeltungswaffe 2” (“Retaliation Weapon 2”), or V-2, framing its use as retaliation, or “payback,” for Allied bombing raids. Many historians note that the rocket attacks inflicted little damage to Allied military capability due to the V-2’s inaccuracy, serving primarily as terror campaigns against civilian populations. Furthermore, according to researchers at the Smithsonian Institution, more concentration camp workers died constructing V-2s than the rockets killed in attacks.

After Germany’s World War II surrender, Project Overcast and Project Paperclip relocated roughly 1,600 German scientists to the United States and captured several A-4 / V-2 rockets, support materials, and technical documents. Similarly, the Soviet Union captured German rocket systems, documentation, and scientific personnel during Operation Osoaviakhim. The appropriated A-4 rocket design and support materials then provided the developmental foundation for several systems that pioneered the Space Age. This included the Soviet R-7 rocket, which launched Sputnik 1, the world’s first artificial satellite, and the Juno 1 rocket, which launched Explorer 1, America’s first satellite. These successes would lead to humans exploring the moon with the Apollo missions and assist with the opening of several technological space frontiers, including meteorological satellite development and evolution.